Indoor Magnetic Positioning with An Array of Magnetic Field Sensors

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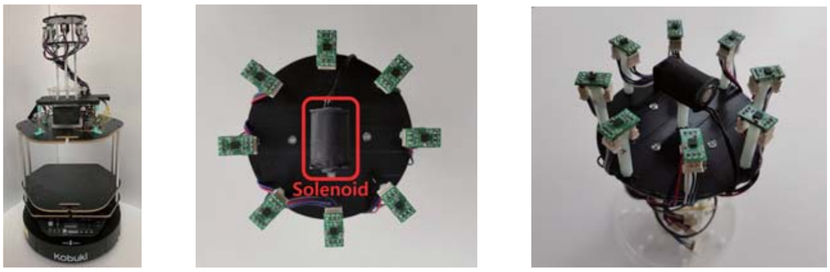
Abstract. One of the most advanced navigation technologies in recent years is called SLAM. It is a technology that maps the environment through a robot's sensing system while exploring an unknown environment. This allows the robot to position itself and to reach its final destination through the created map.
In this paper, we introduce a base technology to apply to SLAM using our new magnetic field sensing system. A magnetic field sensing systems were applied instead of visual sensors or distance sensors for the localization of robots in an indoor environment instead of a visual and distance sensors in this paper. Using surrounding magnetic field system can estimate the current global position of the robot and the direction of nearby magnetic objects. Finally, we show correct positioning of the robot through experiments using odometrical and magnetic field information in a real world learned indoor environment.

Keywords: Magnetic Field Positioning, Navigation, Magnetic Field Sensing System.

1 Introduction

There has been a considerable amount of development in navigation in recent years. Among the technologies that have emerged in this area, SLAM is one of the key technologies for autonomous driving. SLAM can identify the current location and position relative to the overall environment to estimate the destination [1–3]. The technology underlying this SLAM technology is positioning. Positioning allows the robot to determine its position, speed and path. It is also possible to obtain errors of its position on a given map and update its position. For example, path integration technology allows location information to be known using only internal elements such as the rotation of the robot's motor or wheel size as the robot moves [4, 5]. However, odometrical errors tend to accumulate due to mechanical errors of the motor or slipping on the floor surface as the actual robot moves. To overcome this, there are many studies that use various sensing systems. For instance, robots use visual sensors or recently Lidar sensors to obtain location information and the distance between surrounding objects and



(a) (b) (c)

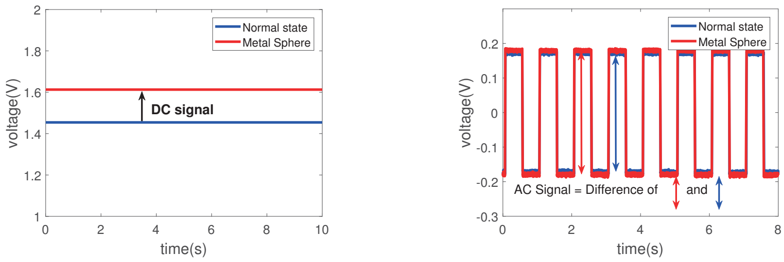
Fig. 1. Magnetic Field Sensing System (a) The system is attached to the Mobile Robot(Turtlebot). (b) A diagram of the array of magnetic field sensors.

the robot. Thus, before the navigation technology is implemented, positioning and localization technologies identify location and status information.
In this paper, we introduce a magnetic positioning technology using a magnetic field sensing system. This magnetic field technology is also based on biomimetic technology. As we all know, there is a huge magnetic field signal in nature coming from the Earth and many animals and insects use this geomagnetic field for survival. The ultimate goal of this study is to obtain the positioning technology based on magnetic field.
To do this, we applied the magnetic field sensing system to the positioning technology in an experimental environment and updated the robot's position using magnetic field information. We performed real-life experiments by attaching a magnetic field sensing system made by our team to a mobile robot. The experiment was conducted in a compact space inside a laboratory. We measured the sensor values in the sensing system and conducted mapping based on magnetic objects. We used a total of 72 points at 10 cm intervals and checked the limitations and the sensitivity of the sensing system. Through this study, we were able to verify the possibility for laying the foundation of magnetic field based navigation technology.

2 Method & Experiments

2.1 Magnetic Field Sensing System

The magnetic field sensing system we introduced in this paper consists of eight analog sensors and a 12-V DC solenoid by placing eight of these analog magnetic field sensors in a circular 45 degree interval, as shown in Fig. 1. From this magnetic field sensing system, we can obtain two kinds of signals. We define these signals as DC and AC signals as shown in Fig. 2. The DC signal is defined as the change in voltage that can be obtained when the solenoid is switched on. The AC signal refers to the amplitude of the voltage change when the solenoid is switched on. Details of the configuration of this sensing system are described in [6].

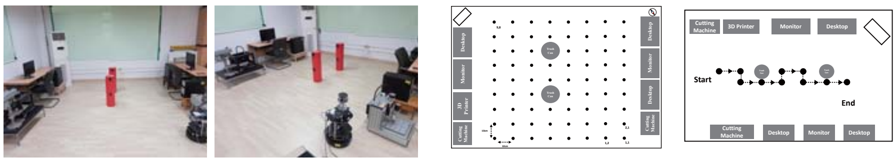


(a) (b)

Fig. 2. The two type of signals the sensing system can detect. (a) is DC signal, (b) is AC signal.

2.2 Experimental Setting

The experiment was carried out in a indoor laboratory of 350cm x 400cm size in Fig. 3. Three computer desktops and monitors were placed on the outside, and two metal trash cans were placed in the center. The surrounding magnetic field of experimental environment was measured by the magnetic field sensing system of the robot at each point as it moved at intervals of 10 cm through a total of 72 points. Using the data obtained from these experimental environments, a Magnetic Experience Map (to be introduced in the following sections) was constructed. Also, as shown in (d) of the Fig. 3, seven steps were performed and the current location was updated through our matching method with the magnetic experience map.

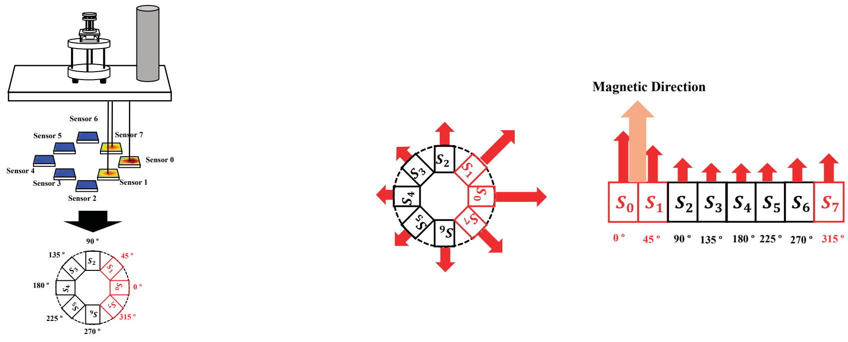


(a) (b) (c) (d)

Fig. 3. Experimental Environment. (a) is the front view, (b) is the side view and (c) is the diagram of experimental environment. (d) is the path of the robot test based on user's command.

2.3 Creating the Magnetic Experience Map

There are two main ways to form the magnetic experience map : using the largest of eight sensor values and then expressing all eight sensors in Fig. 5. The first method shows how a magnetic field is topologically formed for the



(a) (b)

Fig. 4. The method of creating a magnetic map and estimating the magnetic direction.

experimental environment. The second method allows us to visually estimate the direction of the magnetic objects. The map is created according to the two types of signals mentioned earlier, DC and AC. Through this map, we implemented robot behavior using existing memory or experience.

2.4 Magnetic Direction

As mentioned in the system configuration section earlier, this magnetic field sensing system uses eight sensors for sensing the surrounding magnetic objects as shown in (b) of Fig. 4. Since the sensing system is circular, it can be used to detect all directions as the robot moves. The magnetic field sensing information can be used to determine or estimate the direction of the surrounding magnetic object. This method was motivated by sand scorpions and was implemented through the following formula.

$$ze^{i\phi} = \sum_{k=1}^{m} z_k e^{i\phi_k} = x + yi \tag{1}$$

$$x = \sum_{k=1}^{m} z_k \times cos(\phi_k), \qquad y = \sum_{k=1}^{m} z_k \times sin(\phi_k) \tag{2}$$

$$\phi = arctan(y/x) \tag{3}$$

ϕ is the direction of the vibration signals, and the score for each leg of the sand scorpion is z_k(m=8), and the degree of each leg is ϕ_k, which can be expressed as above equations [7]. In Eq. (1), $z_k e^i \phi$ can be expressed with cosine and sine values through Euler formula. Then, according to the score and degree of each leg, it can be expressed as Eq. (2). The values of x and y can be obtained through Eq. (2) and the direction of the vibration's source (ϕ) can be estimated through Eq. (3) [7, 8]. Therefore, the direction of the vibration's source can be obtained using the AC and DC signals instead of the arrival time of the vibration signal with the above equations.

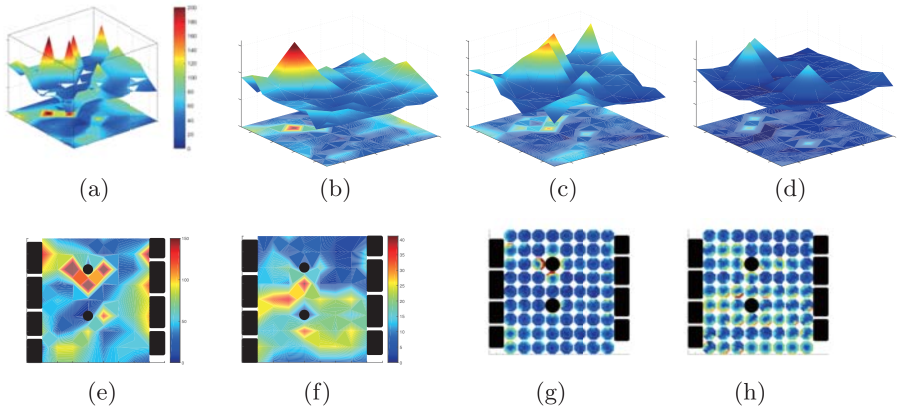


Fig. 5. Data expression of the magnetic map using the maximum value of sensing values. (a) is the intensity of value sensing value, (b) is value the x-axis, (c) is value the y-axis and (d) is value the z-axis. Magnetic Mapping(Experience Map). (a) and (c) is the DC value of the given environment. (b) and (d) is the AC value of the given environment.

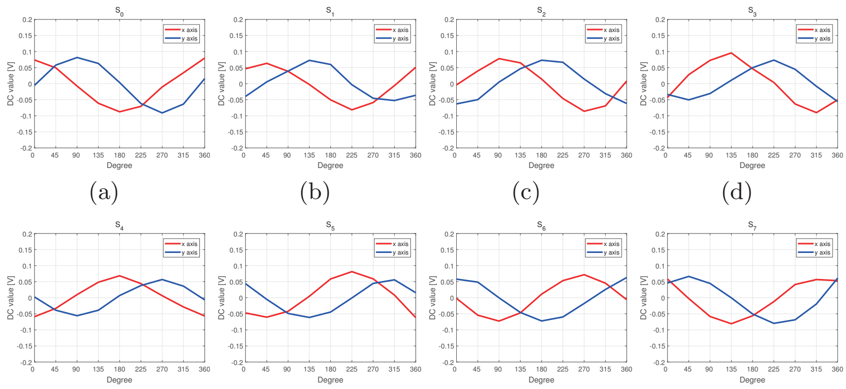
2.5 Magnetic Matching Method

In this paper, we update the robot's position through matching method with the magnetic field information measured in the magnetic environment map. This matching method is largely divided into two stages. The first is to compare the information obtained from the magnetic direction and the experience map obtained at a specific location. At this time, comparing directions would result in several candidate groups. To reduce this candidate group, we compare the magnetic field sensing values. This is the second step. When the candidate group that came through these two steps and the current robot is ordered to go to a specific location, the point closest to that particular location is finally selected.

3 Results

3.1 Global Direction

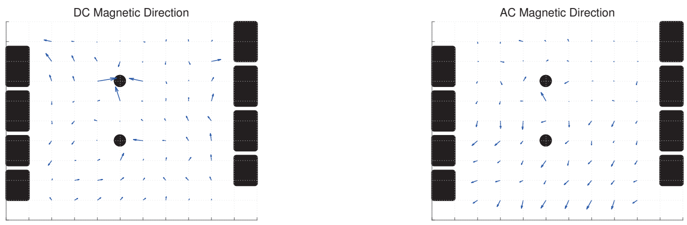
Through the magnetic field sensing system, we can estimate the global magnetic direction of the robot. In other magnetic field sensing systems, when detecting surrounding magnetic objects through one magnetic field sensor, the magnetic object cannot be utilized as a compass due to disturbance. In contrast, since the system has multiple sensors, sensors that do not receive disturbance from magnetic objects can recognize signals from the magnetic field of the earth. As shown in Fig. 6, signals are obtained by rotating each sensor clockwise with regard to the east direction. The signals from the eight sensors can be obtained with specific x,y values according to their direction, and can therefore detect the global direction of the robot.



(a) (b) (c) (d)

(e) (f) (g) (h)

Fig. 6. The DC value of each sensor during rotating. For the z-axis, the values are constant because the magnetic field sensing system rotates in place with the same height, and data are obtained. (a): sensor 0, (b): sensor 1, (c): sensor 2, (d): sensor 3, (e): sensor 4, (f): sensor 5, (g): sensor 6, (h): sensor 7.

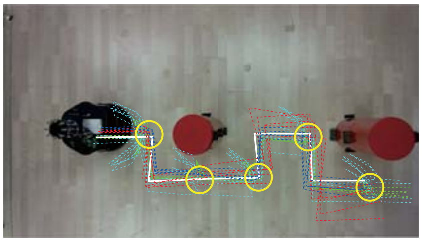


(a) (b)

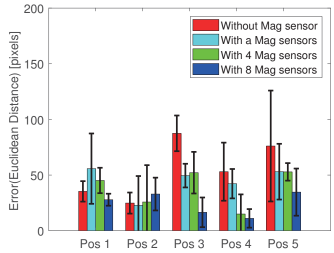
Fig. 7. The Magnetic Direction of DC and AC. (a) is DC Magnetic Direction, (b) is AC Magnetic Direction.

3.2 Magnetic Direction

In this paper, the robot can detect the direction of magnetic objects around it using information obtained in the experimental environment. We can obtain the magnetic direction by using the formula (1),(2),(3) in the method section. This can be applied to avoidance by recognizing magnetic obstacle as the robot moves in the actual indoor environment, and also to determining the exact location of its route. As shown the Fig. 7, the direction is given for magnetic fields with strengths larger than a certain size. This allows for the representation of DC signals and AC signals, respectively. Where DC signals can be determined at various points in the macro, AC signals can be determined at a location close to their own objects, but there is some noise. In fact, in the [6] paper studied by us, the difference between DC and AC was demonstrated through experiments. A specific path was set based on the magnetic object (metal trash can), and the



(a)



(b)

Fig. 8. The trajectory of the robot experiment(a) and the comparison of Errors(b). White line is the user's command and red dashed line is the trajectory without the magnetic field information and the blue dashed line is the trajectory the robot with the magnetic field information. The green dashed is the trajectory using only four sensors' information and the cyan dashed line is the trajectory using only one sensor placed on the head of the robot. The yellow circles are the updating positions.

matching method was used to update the current position using magnetic field information while giving a command to the robot. In fact, in [6], we studied the effect of DC and AC signals and it was demonstrated through experiments.

3.3 Robot Positioning

The results were compared with the results of moving the robot without magnetic field information on a designated path based on user's command and using magnetic field information. Also, the results were divided into three types. The first type is to update the path of the robot using magnetic information from one magnetic field sensor placed in the head direction of the robot. As shown in cyan color line of Fig. 8, based on the surrounding magnetic field information obtained from one sensor, the results are updated with an odometrical error. Since one sensor is used to find the magnetic direction we performed a rotation action. In the 5 update positions, the average error is about 48.71 pixels (29.22 cm) which is similar to a method that does not use a magnetic field. Basically, one pixel is corresponding to 0.6 cm for distance. The second type is to use only four sensor information out of a total of eight sensors in the front, rear, and side directions (e.g., north east and west). This type was less rotated than the first type, and the robot can find the magnetic direction in the magnetic experience map and update it, as shown in the green dashed line of Fig. 8. The average error of the second type is 39.75 pixels(23.85cm). The last type is to use all eight sensor information that can be obtained from magnetic field sensing systems. Unlike the previous first and second types, the robot can update its position without rotation action as shown in the blue dashed line of Fig. 8. The average error is also 24.63 pixels (14.77 cm). The average error value for 5 iterations of robot test is 47.45 pixels (28.47 cm) when the magnetic field information is not used as shown in the red dashed line of Fig. 8, and if the surrounding magnetic field information of the magnetic sensing system is used, it can be seen that the robot can reach the specified position based on user's command in (b) of Fig. 8.

4 Conclusion

In this paper, by using the magnetic field sensing system developed by us, a magnetic experience map of the experimental environment could be obtained, and the global direction could be determined through the array of magnetic field sensors. In addition, the robot was positioned in an indoor laboratory environment and the direction of the magnetic object around it was used to position its current position. Basically, sensing systems and methods for determining the orientation of magnetic objects were constructed based on biomimicry. In the robot experiment based on the command of actual users, the results were better than the experiments obtained by using only the robot's odometrical information, and we obtained more accurate results by using 8 sensor data of 2 types through the array of 8 sensors and the solenoid at the center. This proved the sensing system suitable for the positioning technology based on indoor navigation.

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References

1. Wolcott, Ryan W., and Ryan M. Eustice. "Visual localization within lidar maps for automated urban driving." 2014 IEEE/RSJ International Conference on Intelligent Robots and Systems. IEEE, 2014.
2. McDonald, John, et al. "6-DOF multi-session visual SLAM using anchor nodes." (2011): 69-76.
3. Milford, Michael, and Gordon Wyeth. "Mapping a suburb with a single camera using a biologically inspired SLAM system." IEEE Transactions on Robotics 24.5 (2008): 1038-1053.
4. McNaughton, Bruce L., et al. "Path integration and the neural basis of the'cognitive map'." Nature Reviews Neuroscience 7.8 (2006): 663.
5. Franz, Matthias O., and Hanspeter A. Mallot. "Biomimetic robot navigation." Robotics and autonomous Systems 30.1-2 (2000): 133-153.
6. Kang, Byungmun, and DaeEun Kim. "Detecting a Sphere Object with an Array of Magnetic Sensors." International Conference on Simulation of Adaptive Behavior. Springer, Cham, 2018.
7. Kim, D. "Neural network mechanism for the orientation behavior of sand scorpions towards prey." IEEE transactions on neural networks 17.4 (2006): 1070-1076.
8. Adams, Samantha V and Wennekers, Thomas and Bugmann, Guido and Denham, S and Culverhouse, Phil F, 'Application of arachnid prey localisation theory for a robot sensorimotor controller", Neurocomputing, Vol. 74, No. 17, pp. 33353342, 2011.